PHEV'09 Plug-In Hybrid and Electric Vehicles September 28 to 30, 2009 – Montreal

Véhicules électriques et hybrides rechargeables 28 au 30 septembre, 2009 – Montréal

Idaho National Laboratory

U.S. Department of Energy's Vehicle Technologies Program -

PHEV Testing and Demonstration Activities Conducted by the U.S. Department of Energy's AVTA

Richard 'Barney' Carlson, Jim Francfort, Mindy Kirkpatrick, Matt Shirk, John Smart
Idaho National Lab

September 2009

INL/CON-09-16628

This presentation does not contain any proprietary or sensitive information

AVTA Background and Goals

- The Advanced Vehicle Testing Activity (AVTA) is part of DOE's Vehicle Technology Program
- The Idaho National Laboratory (INL) conducts the AVTA for DOE, with Electric Transportation Engineering Corporation (ETEC) providing testing support. Argonne National Laboratory conducts the dynamometer testing
- The AVTA goals:
  - Provide benchmark data to technology modelers, research and development programs, vehicle manufacturers (via VSATT), and target and goal setters
  - Assist fleet managers in making informed early adopter vehicle purchase, deployment and operating decisions

AVTA Testing by Technology

- **Plug-in hybrid electric vehicles (PHEV)**
  - **12 models, <u>187 vehicles, 1,00,000 fleet test miles</u>**
- **Hybrid electric vehicles (HEV)**
  - **17 models, 45 vehicles, 5.5 million test mile**

- **Neighborhood electric vehicles**
  - **23 models, 200,000 test miles**
- **Hydrogen ICE (internal combustion engine) vehicles**
  - **7 models, 400,000 test miles**

- **Full-size battery electric vehicles (BEVs)**
  - **40 BEV models, 5+ million test miles**
- **Urban electric vehicles**
  - **3 models, 1 million test miles**

12 PHEVs Models in Testing/Demonstrations

- Hymotion Prius (A123Systems)
- Hymotion Escape (A123Systems)
- Ford E85 Escape (Johnson Controls/Saft)
- EnergyCS Prius, 2 models (Valance and Altair Nano)
- Electrovaya Escape (Electrovaya)
- Hybrids Plus Escape, 2 models (Hybrids Plus and K2 Energy Solutions)

- Hybrids Plus Prius (Hybrids Plus)
- Manzanita Prius (lead acid)
- Manzanita Prius (Thunder Sky)
- Renault Kangoo (Saft NiCad)
- (All batteries are Lithium unless noted)

PHEV Testing Methods and Objectives

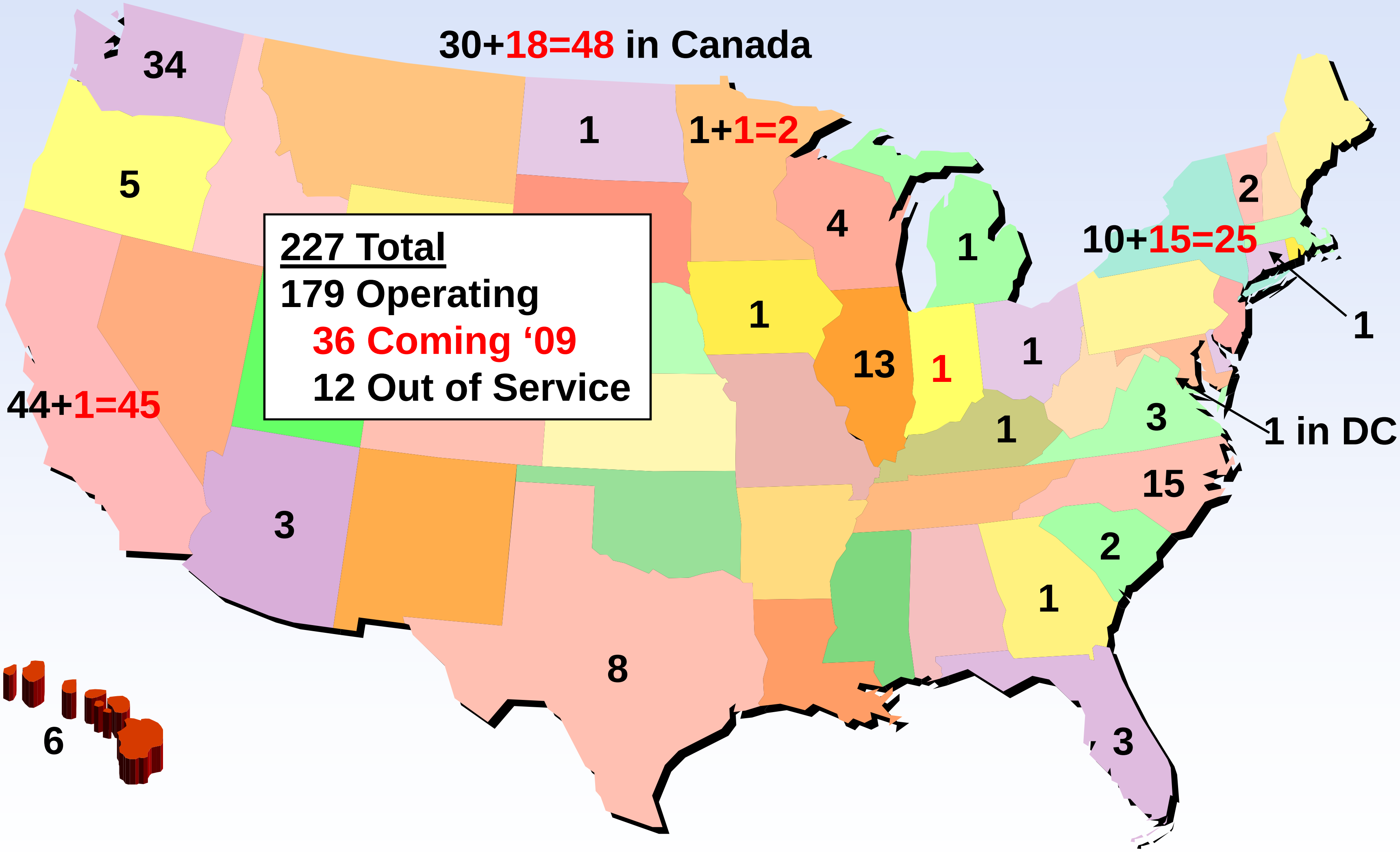
- **Perform independent testing of PHEVs, using:**
  - **Baseline performance testing: closed test tracks and dynamometers**
  - **Accelerated testing: dedicated drivers operating on defined onroad loops**
  - **Fleet testing: everyday unstructured \ non-directed fleet and public use, with onboard data loggers**
  - **Laboratory testing of PHEV batteries**
- **Testing used to document:**
  - **Battery life, charging patterns and profiles**
  - **Vehicle operations, fuel use (electricity and gasoline) and infrastructure requirements**
  - **Driver influences on fuel use**
  - **Individual PHEV models and PHEV concepts**

Fleet Demonstration Partners

- **75+ Testing partners in the U.S. and Canada, including:**
  - **40 Electric utilities and 2 clean air agencies**
  - **10 City, county, state, and province governments**
  - **7 Private companies and advocacy organizations**
  - **8 Universities and colleges**
  - **2 PHEV conversion companies**
  - **1 sea port and 1 DOD facility**
  - **Operating in**
    - **22 U.S. states**
    - **4 Canadian provinces**

PHEV'09 Plug-In Hybrid and Electric Vehicles September 28 to 30, 2009 – Montreal
Véhicules électriques et hybrides rechargeables 28 au 30 septembre, 2009 – Montréal

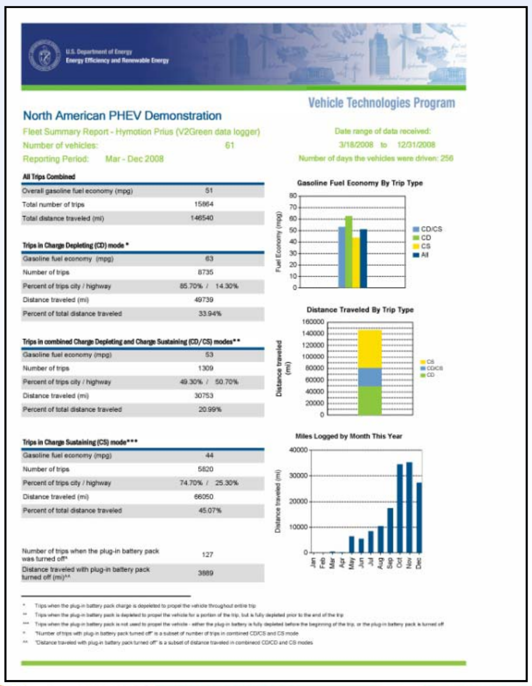
PHEVs and Demonstration Locations



227 Total
179 Operating
36 Coming '09
12 Out of Service

PHEV Fleet Testing Reports

- **Summary reports <u>posted monthly on web</u>**
- **Individual vehicle reports only go to the respective fleets each month, 950+ reports to date (July 1, 2009)**
- **<u>150 Hymotion Prius PHEVs</u>, 710,000 miles, 76,000 trips, 18,000 charging events, 43,000 kWh used. V2Green and Kvaser data logger reports**



U.S. Department of Energy
Energy Efficiency and Renewable Energy

Vehicle Technologies Program

North American PHEV Demonstration

Fleet Summary Report - Hymotion Prius (V2Green data logger)
Number of vehicles: 61
Reporting Period: Mar - Dec 2008

Date range of data received: 3/18/2008 to 12/31/2008
Number of days the vehicles were driven: 256

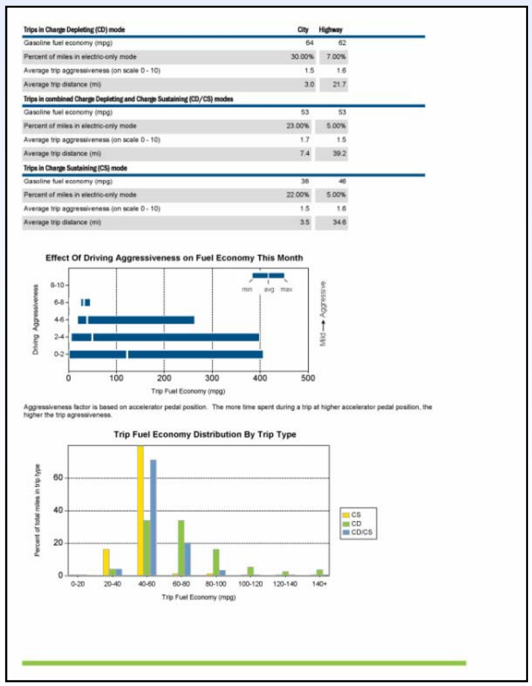
All Trips Combined	
Overall gasoline fuel economy (mpg)	51
Total number of trips	15864
Total distance traveled (mi)	146540

Trips in Charge Depleting (CD) mode *	
Gasoline fuel economy (mpg)	63
Number of trips	8735
Percent of trips city / highway	85.70% / 14.30%
Distance traveled (mi)	49739
Percent of total distance traveled	33.94%

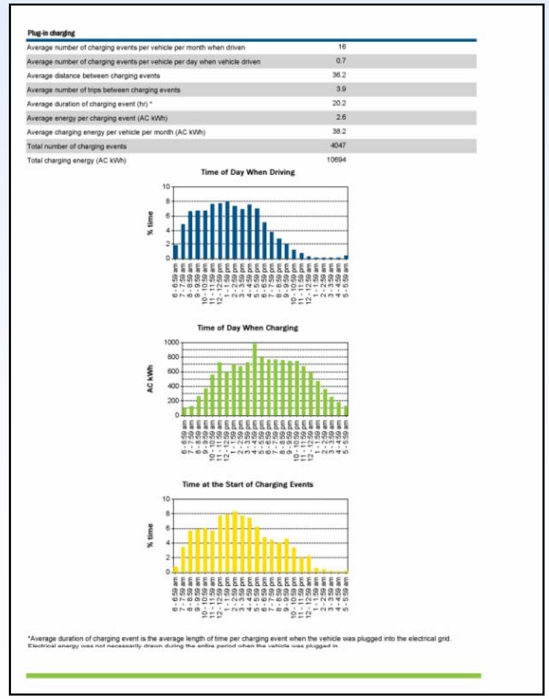
Trips in combined Charge Depleting and Charge Sustaining (CD/CS) modes**	
Gasoline fuel economy (mpg)	53
Number of trips	1309
Percent of trips city / highway	49.30% / 50.70%
Distance traveled (mi)	30753
Percent of total distance traveled	20.99%

Trips in Charge Sustaining (CS) mode***	
Gasoline fuel economy (mpg)	44
Number of trips	5820
Percent of trips city / highway	74.70% / 25.30%
Distance traveled (mi)	66050
Percent of total distance traveled	45.07%

Number of trips when the plug-in battery pack was turned off^	127
Distance traveled with plug-in battery pack turned off (mi)^^	3889



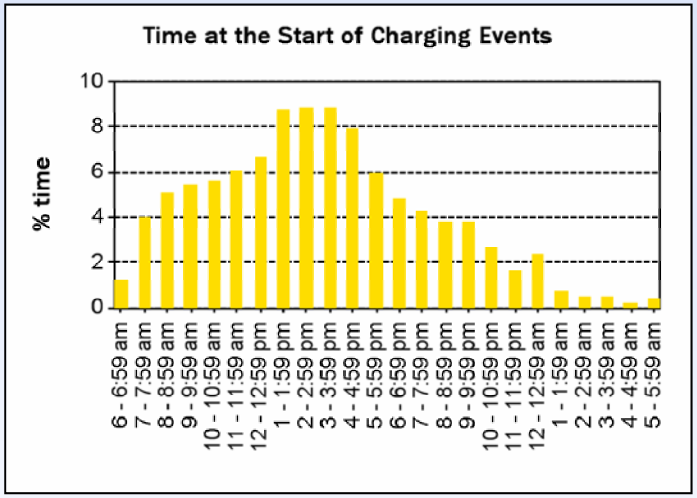
Trips in Charge Depleting (CD) mode	City	Highway
Gasoline fuel economy (mpg)	64	62
Percent of miles in electric-only mode	30.00%	7.00%
Average trip aggressiveness (on scale 0 - 10)	1.5	1.6
Average trip distance (mi)	3.0	21.7
Trips in combined Charge Depleting and Charge Sustaining (CD/CS) modes		
Gasoline fuel economy (mpg)	53	53
Percent of miles in electric-only mode	23.00%	5.00%
Average trip aggressiveness (on scale 0 - 10)	1.7	1.5
Average trip distance (mi)	7.4	39.2
Trips in Charge Sustaining (CS) mode		
Gasoline fuel economy (mpg)	38	46
Percent of miles in electric-only mode	22.00%	5.00%
Average trip aggressiveness (on scale 0 - 10)	1.5	1.6
Average trip distance (mi)	3.5	34.6

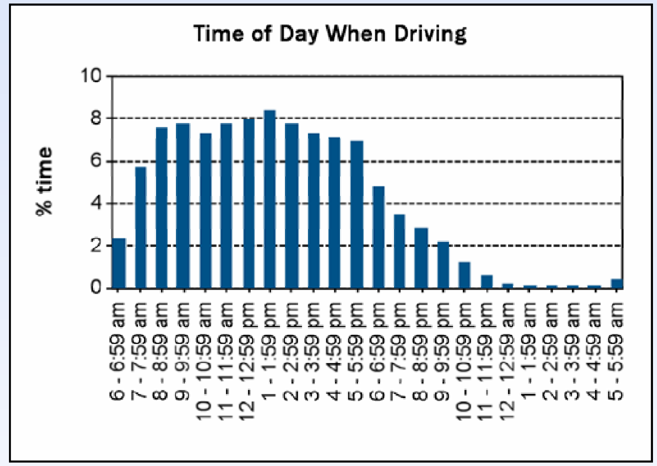


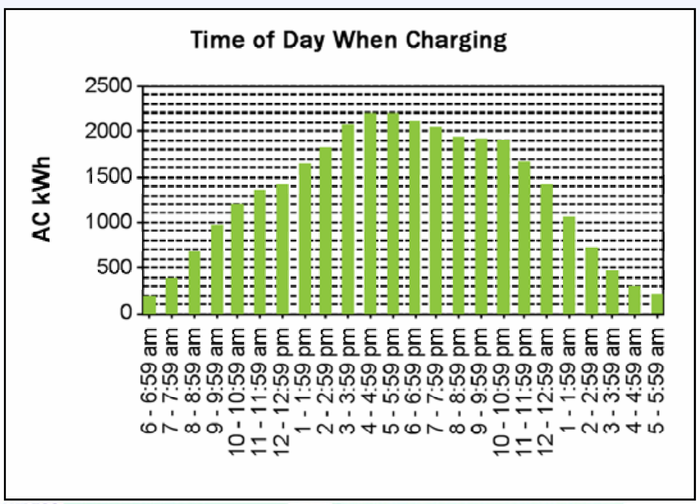
Plug-in charging	
Average number of charging events per vehicle per month when driven	16
Average number of charging events per vehicle per day when vehicle driven	0.7
Average distance between charging events	36.2
Average number of trips between charging events	3.9
Average duration of charging event (hr) *	20.2
Average energy per charging event (AC kWh)	2.6
Average charging energy per vehicle per month (AC kWh)	38.2
Total number of charging events	4047
Total charging energy (AC kWh)	10694

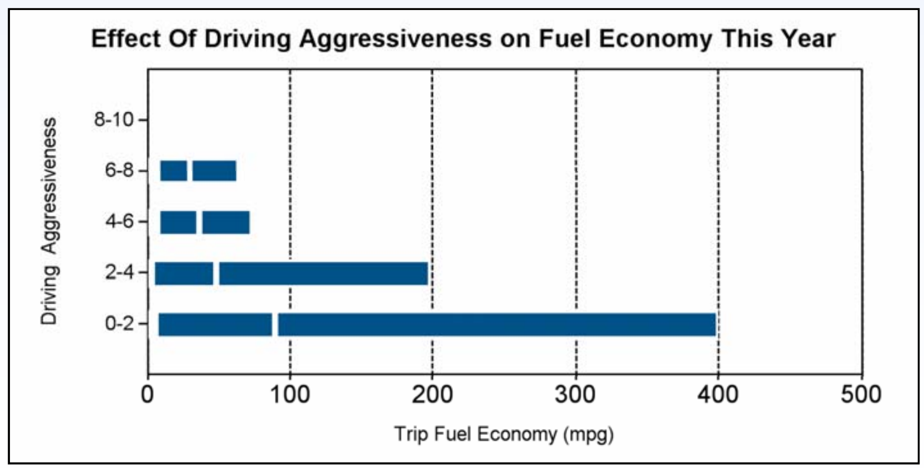
Hymotion Prius (V2Green Logger) Fleet Tests

- **March 01/08 to July 01/09. 110 PHEVs, 498,000 miles, 54,000 trips, 12,400 charging events and 31,000 kWh used**

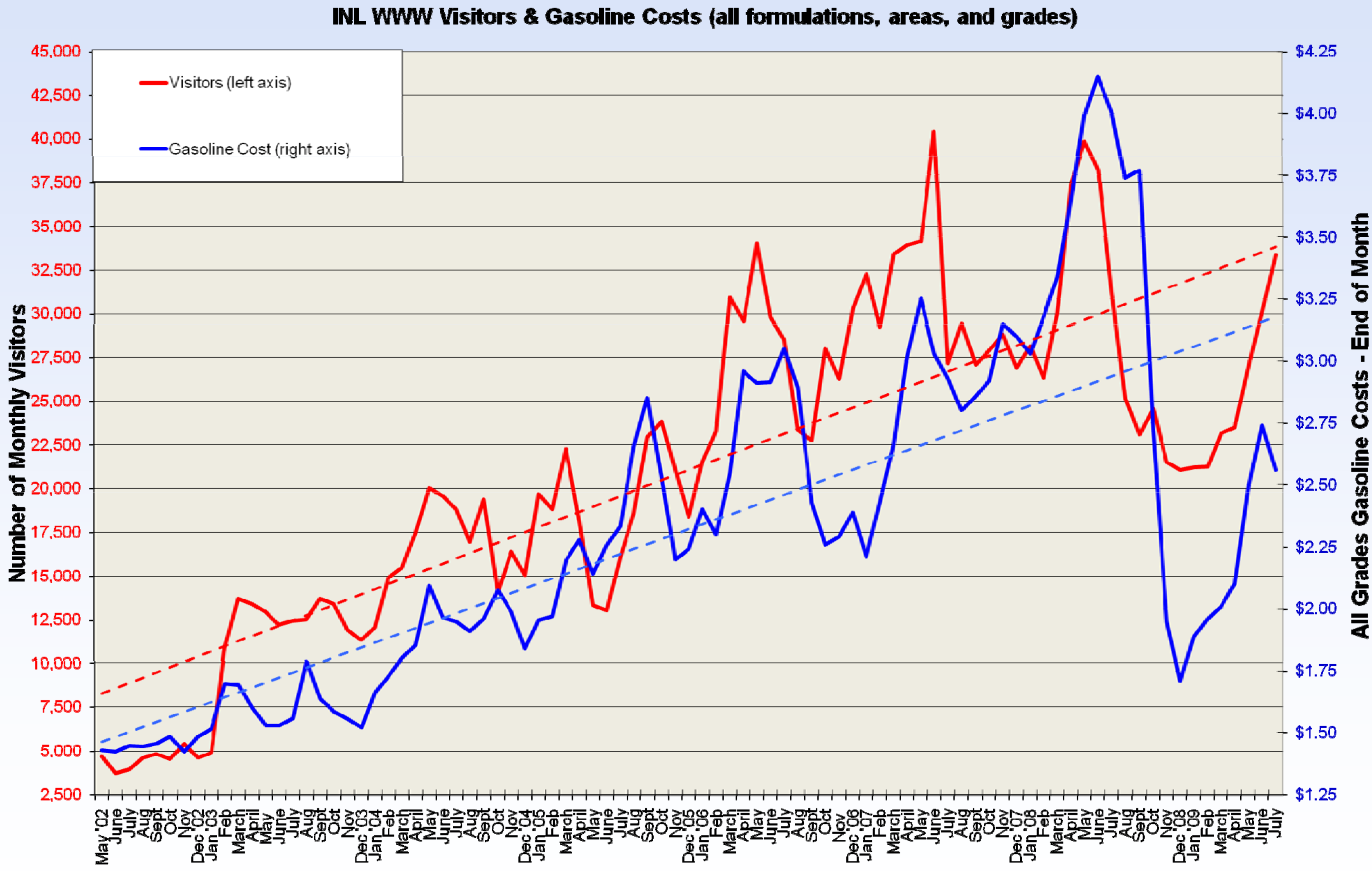








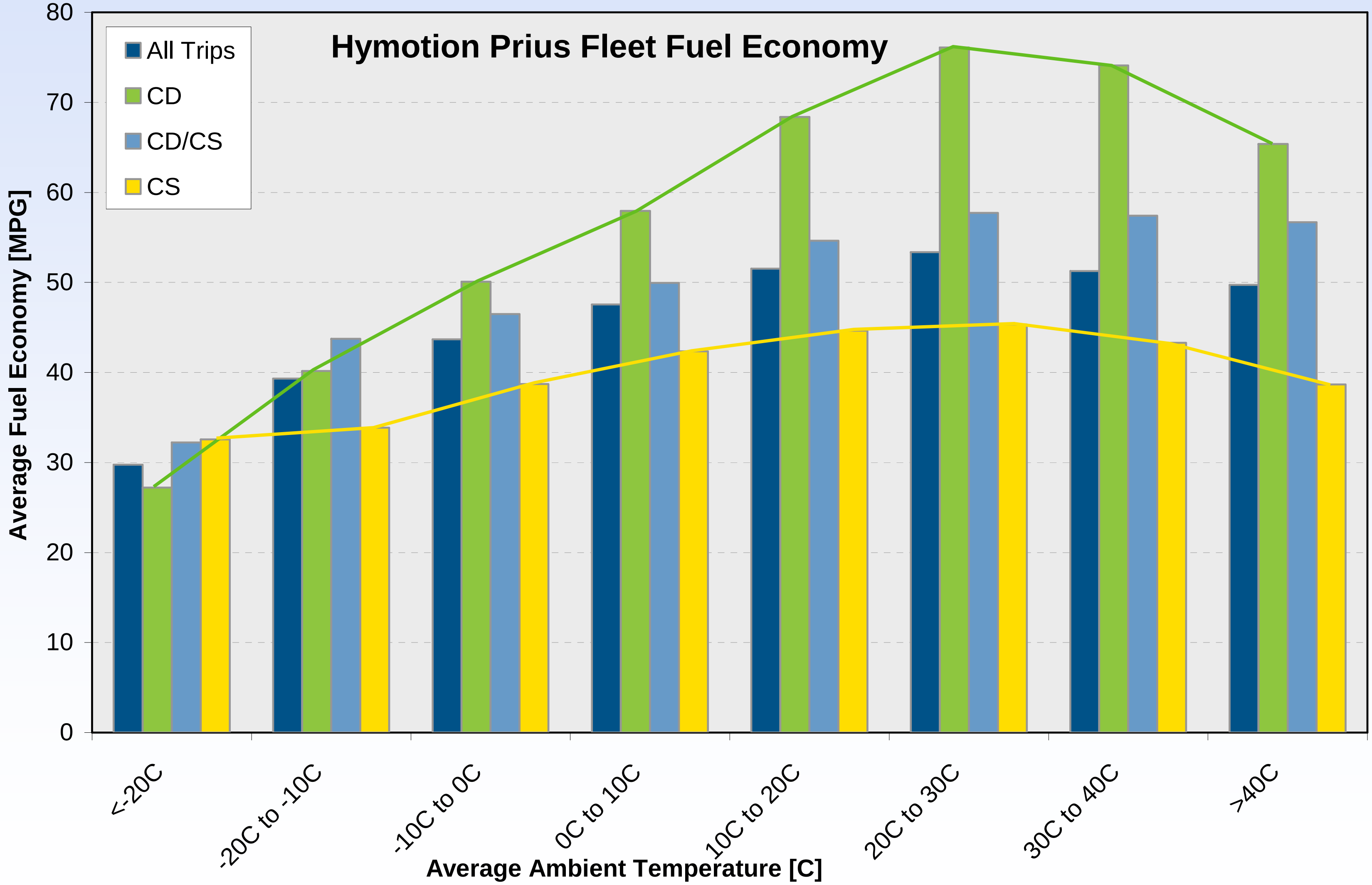
AVTA Webpage Use and Gasoline Costs



Hymotion Prius PHEV

- Conversion PHEV based on Gen II Toyota Prius
- 5 kWh additional battery system installed in rear of vehicle
  - Production NiMH battery is continued to be used
- Power is transferred from the Hymotion Li-Ion batteries to the vehicle through a DC/DC converter
  - Energy transfer is uni-directional
    - Hymotion system is not recharged by regen braking nor engine power
    - Grid energy recharges battery system through on-board charger

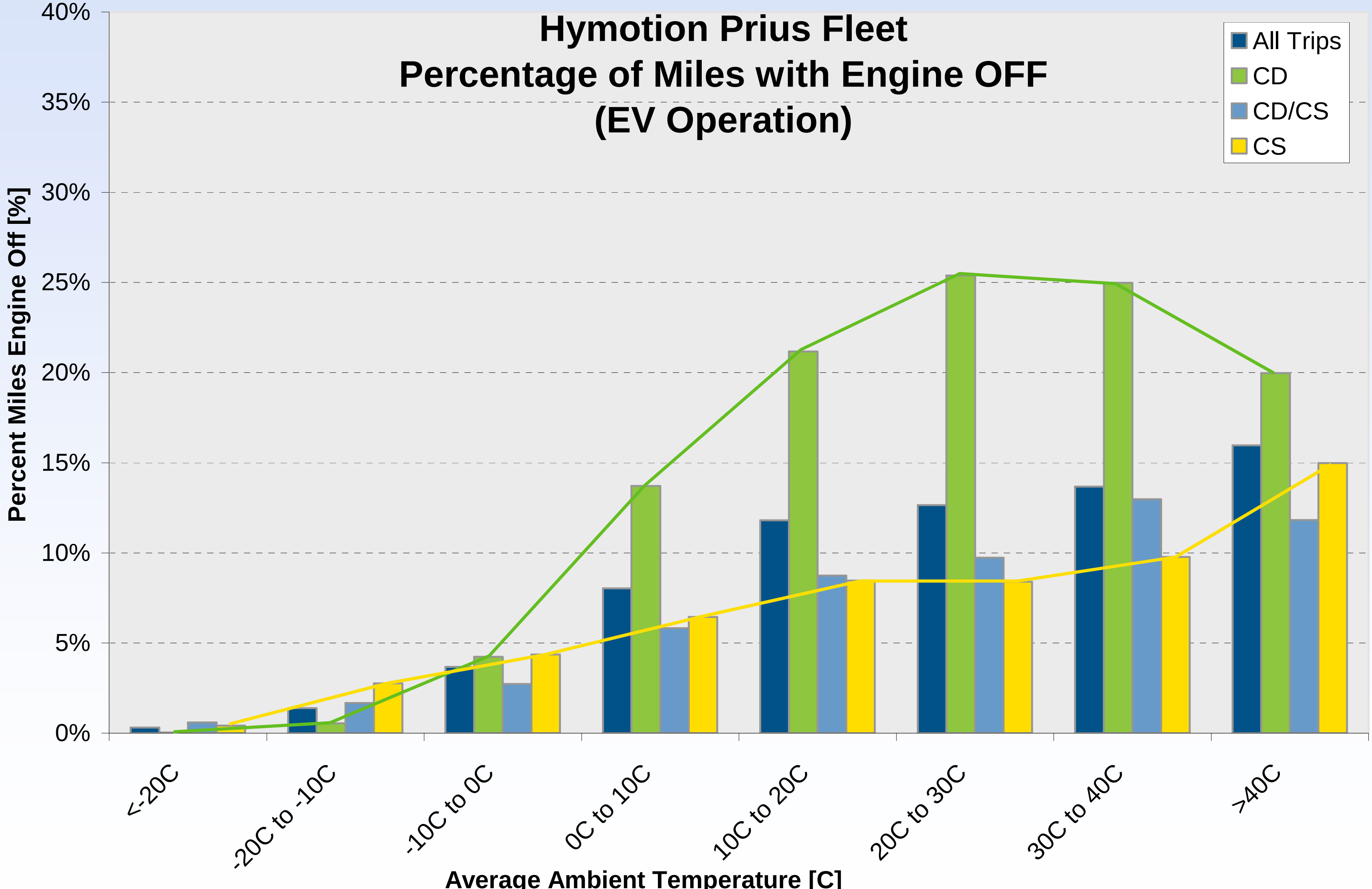
Ambient Temperature Significantly Impacts Fuel Economy of PHEV's



Reasons for Decreased PHEV Fuel Economy at Extreme Temperatures

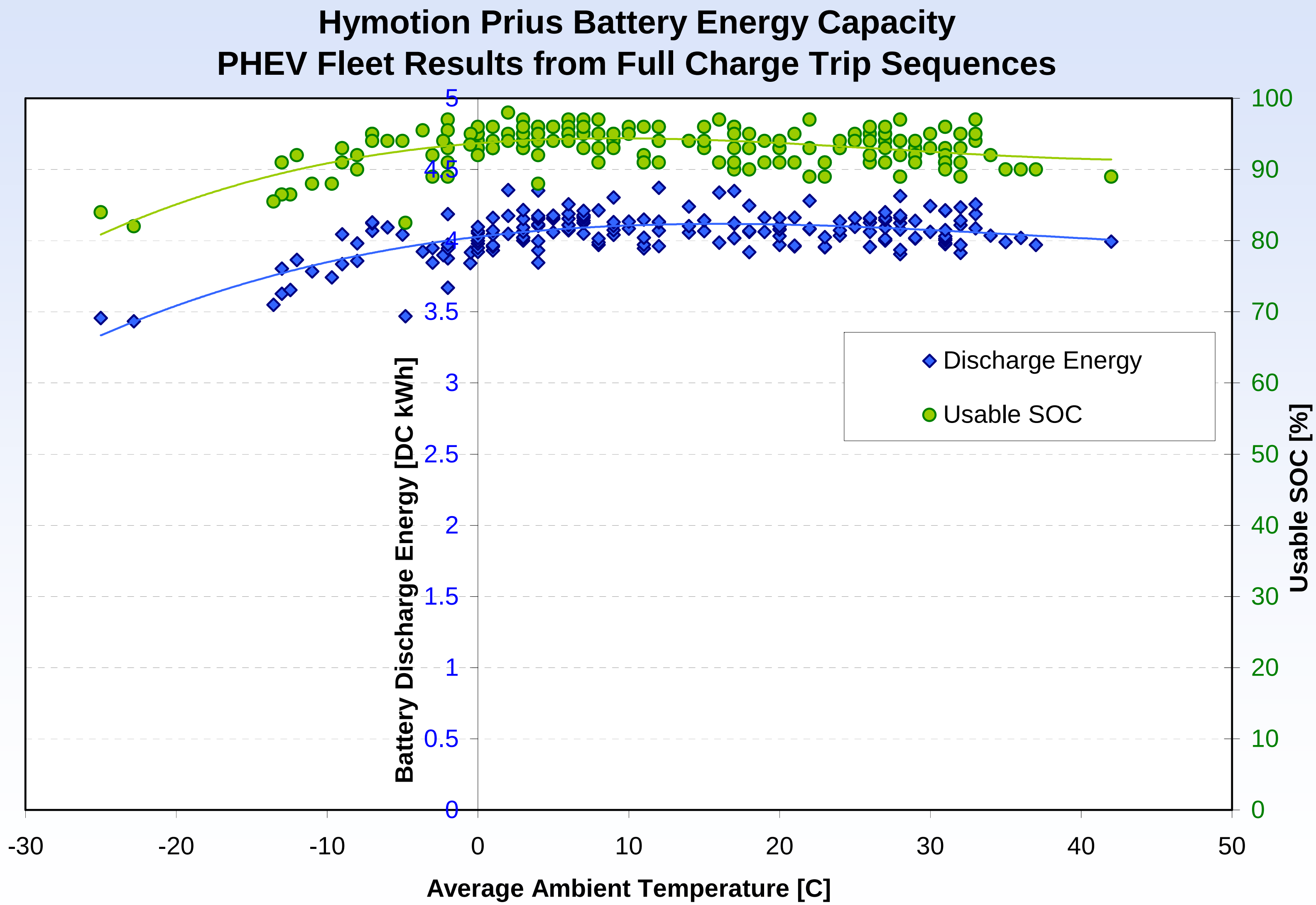
- IC Engine
  - Increased operating time at low temperatures
    - Supply cabin heat
    - Maintain Catalyst temperature for emissions control
  - Decreased Efficiency
    - Increased friction losses at low temperatures
- Battery System
  - Decreased usable energy capacity
  - Decreased power capability
- Accessories using additional energy
  - Air Conditioner
  - Defroster

Engine Operation is a Main Factor for change of Fuel Economy for PHEV's

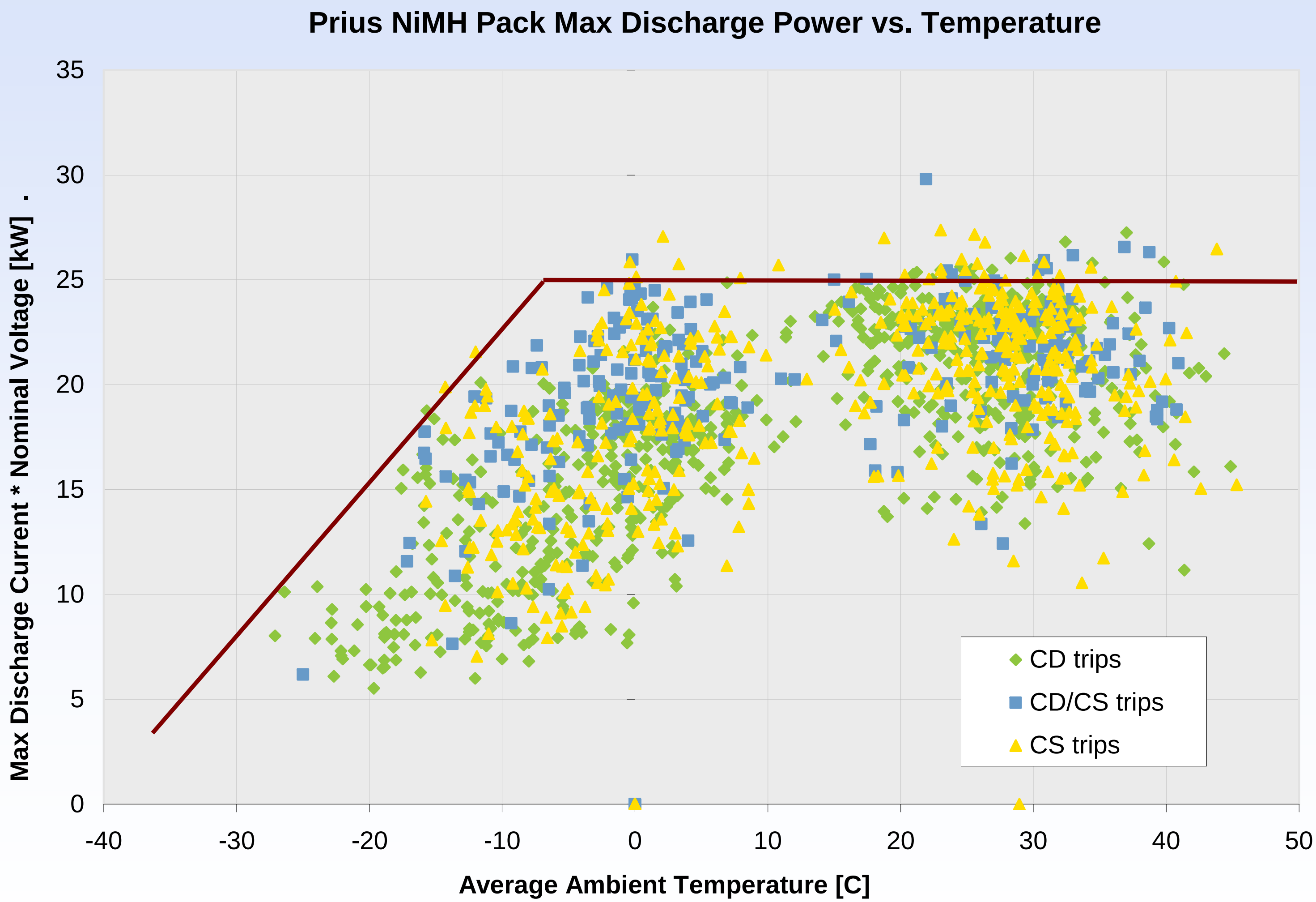


PHEV'09 Plug-In Hybrid and Electric Vehicles September 28 to 30, 2009 – Montreal
Véhicules électriques et hybrides rechargeables 28 au 30 septembre, 2009 – Montréal

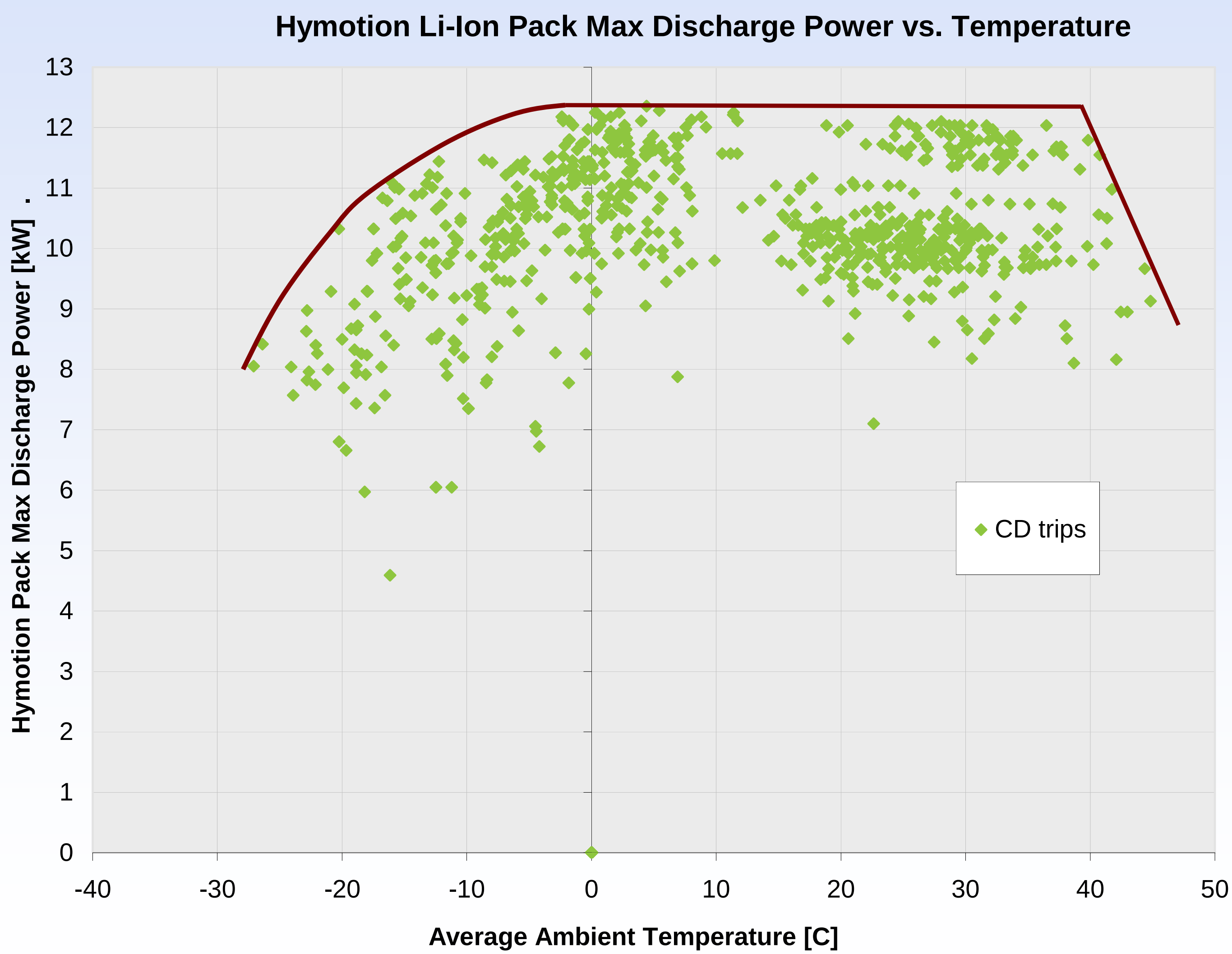
Usable Battery Capacity is Slightly Effected by Temperature



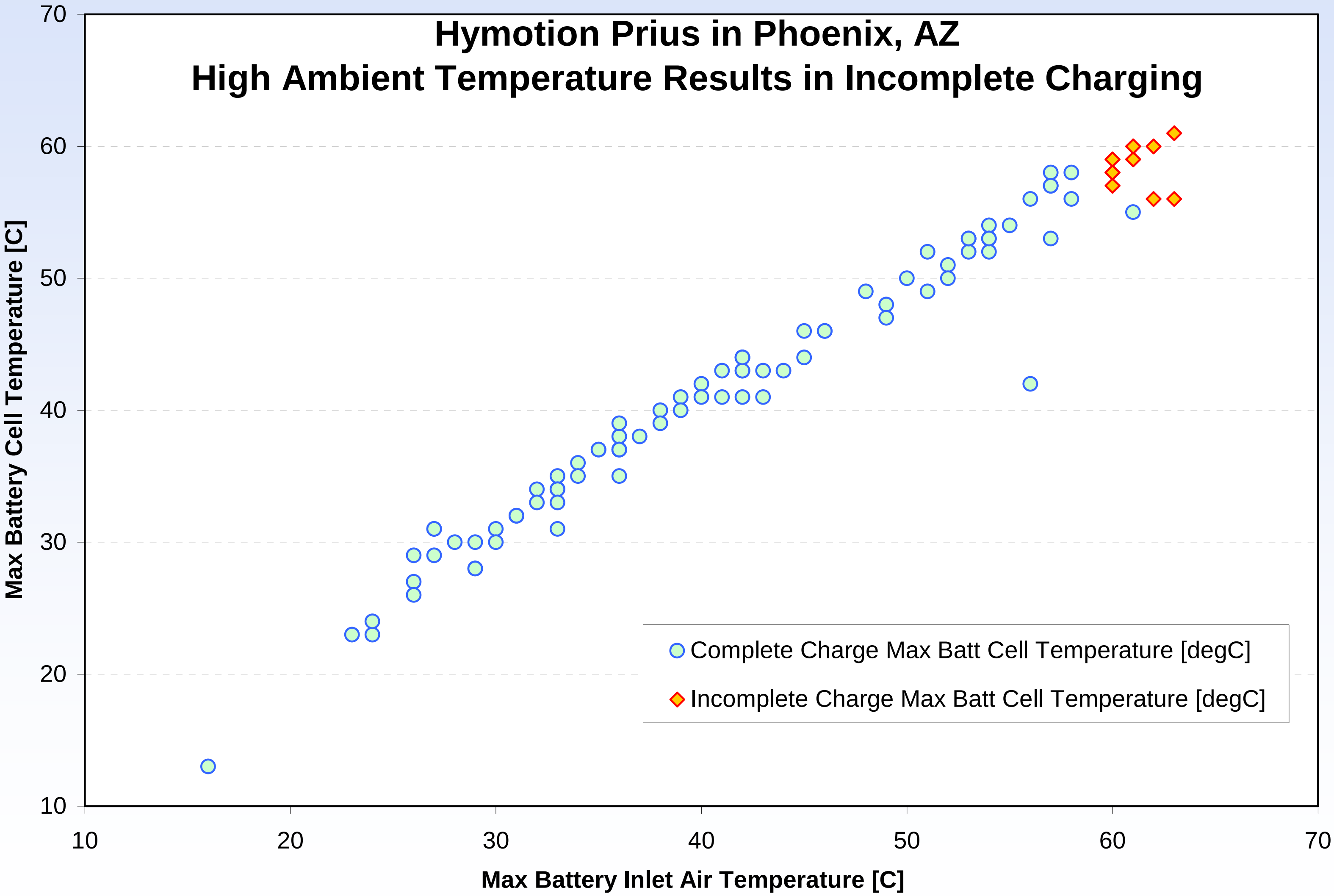
NiMH Battery Power Limitation by Prius Calibration



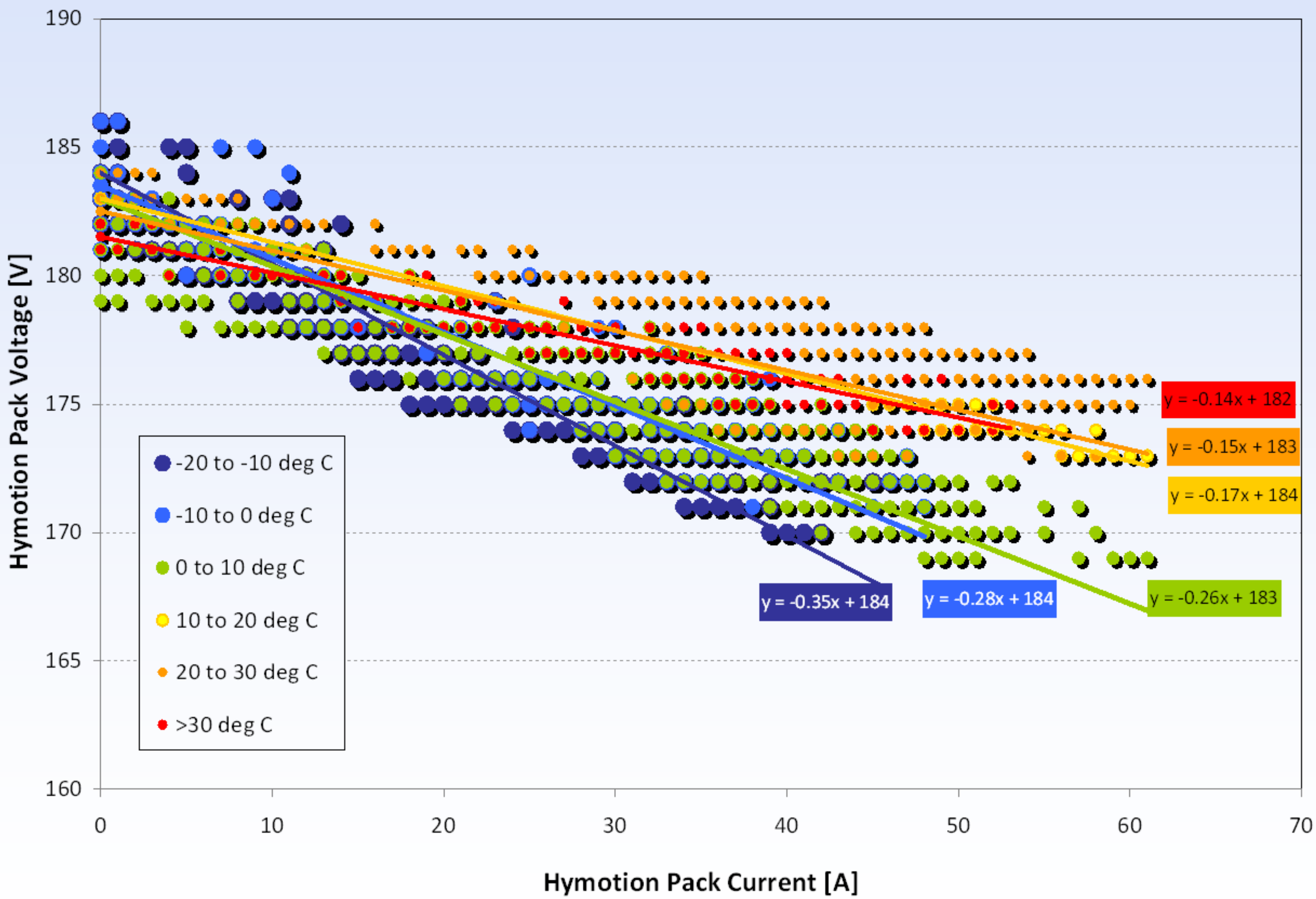
Li-Ion Battery System Power is also Limited by Prius Calibration at Extreme Temperatures



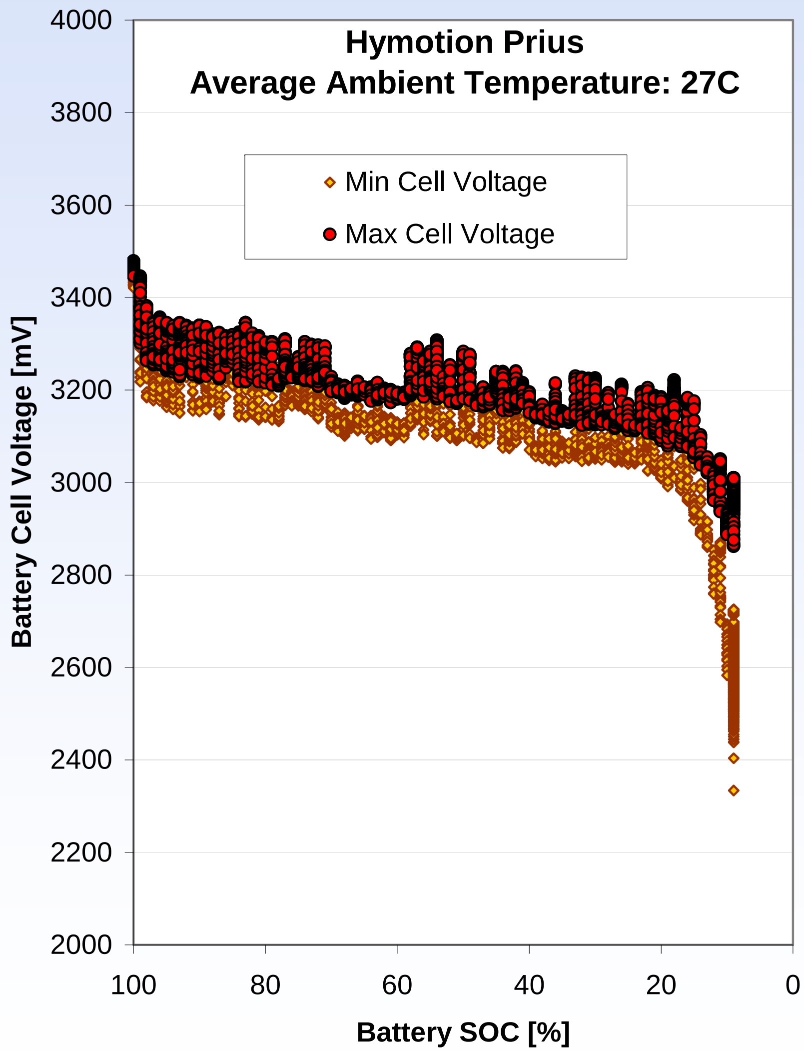
Incomplete Charging Observed at Very High Temperatures

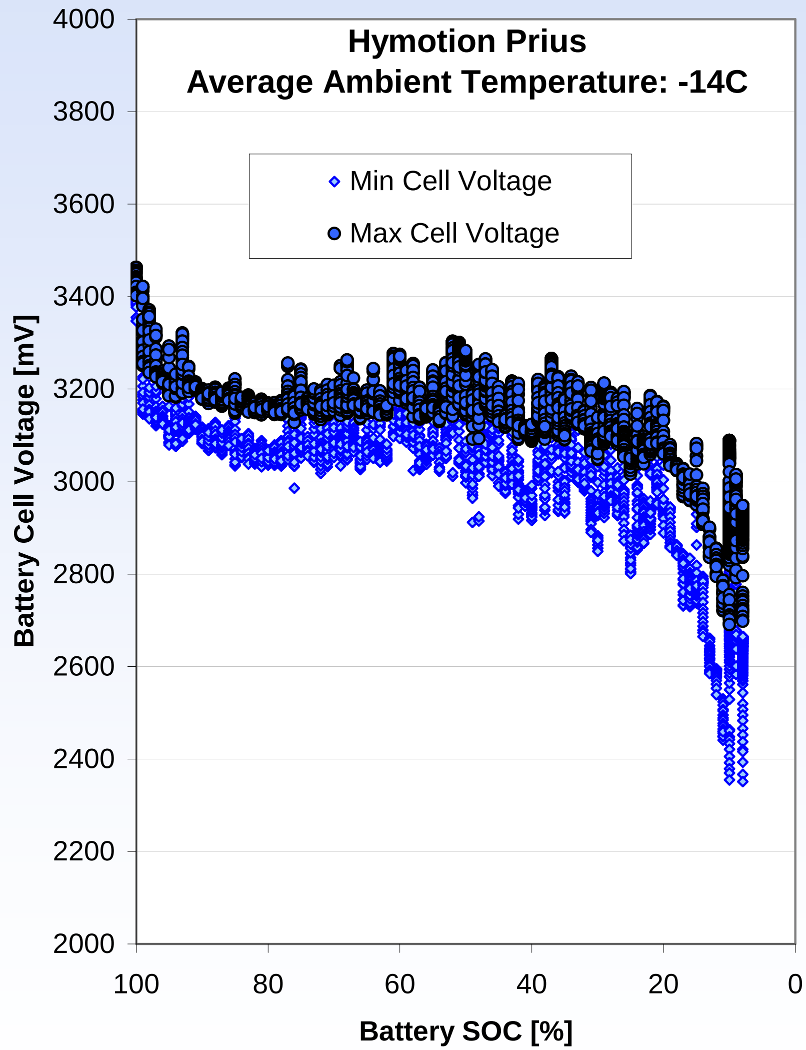


Hymotion Li-Ion Battery Internal Resistance Change with Temperature

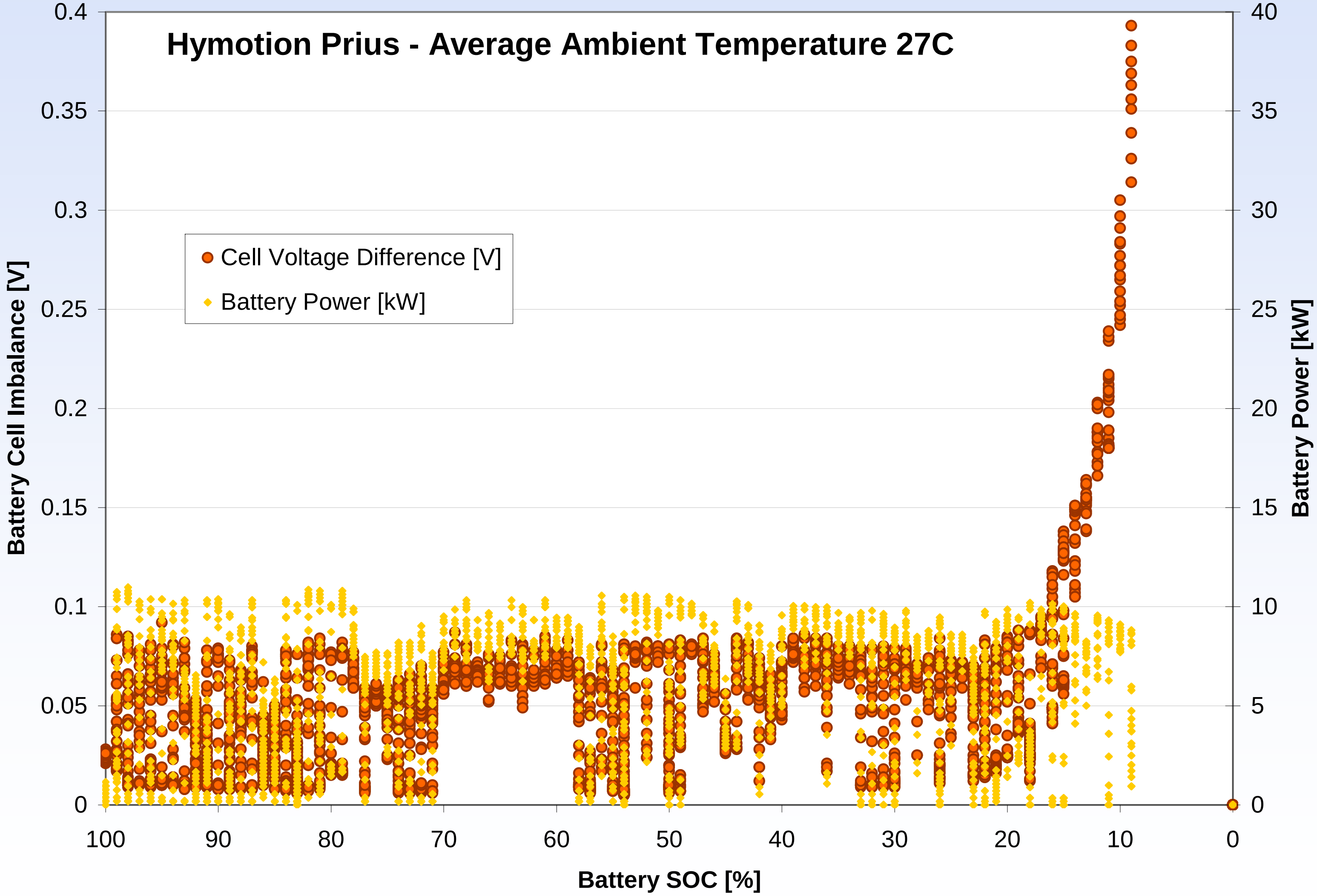


Battery Cell Voltage Varies more at Low Temperatures due to Increase Internal Resistance



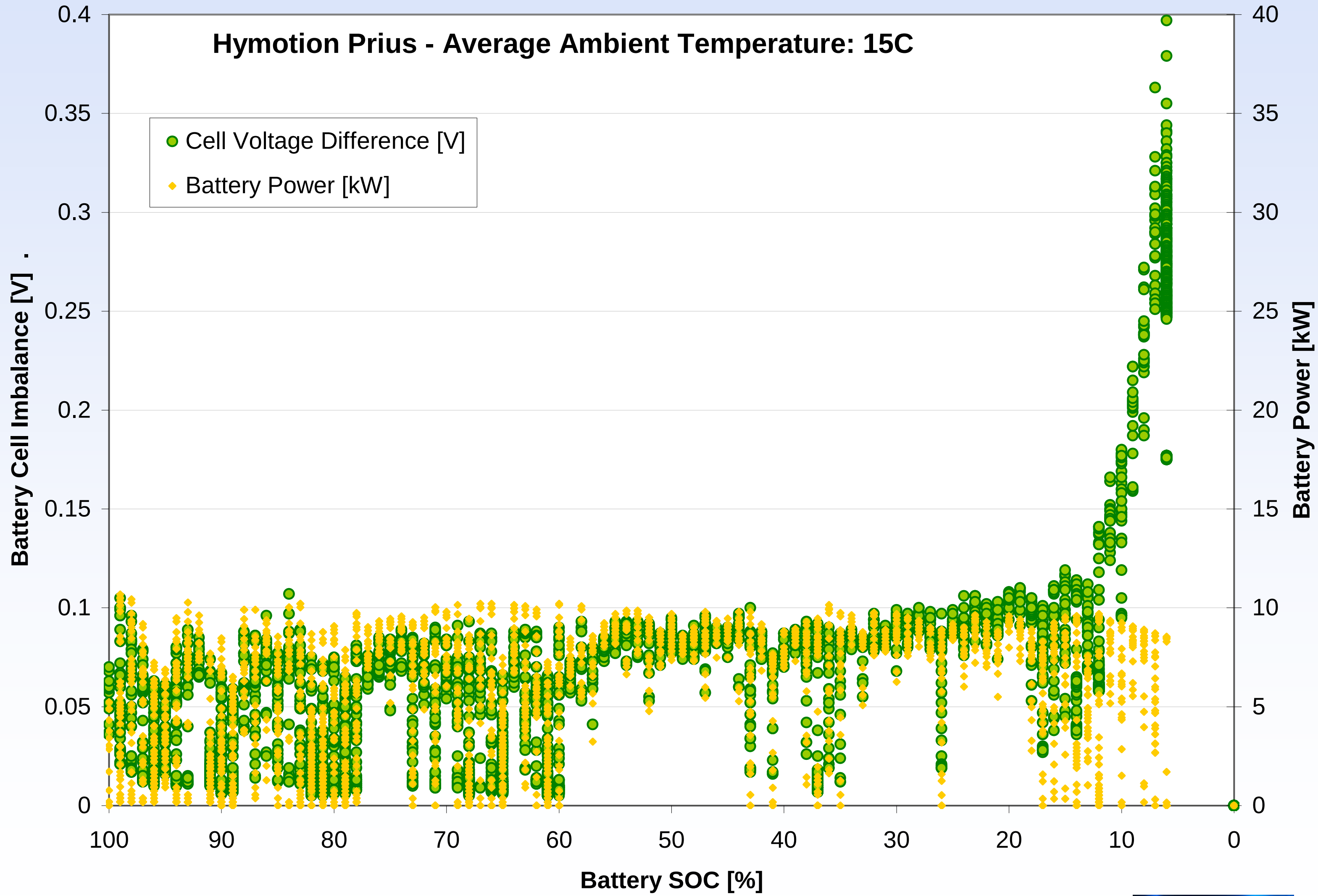


Battery Cells have Moderate Imbalance at Higher Temperatures

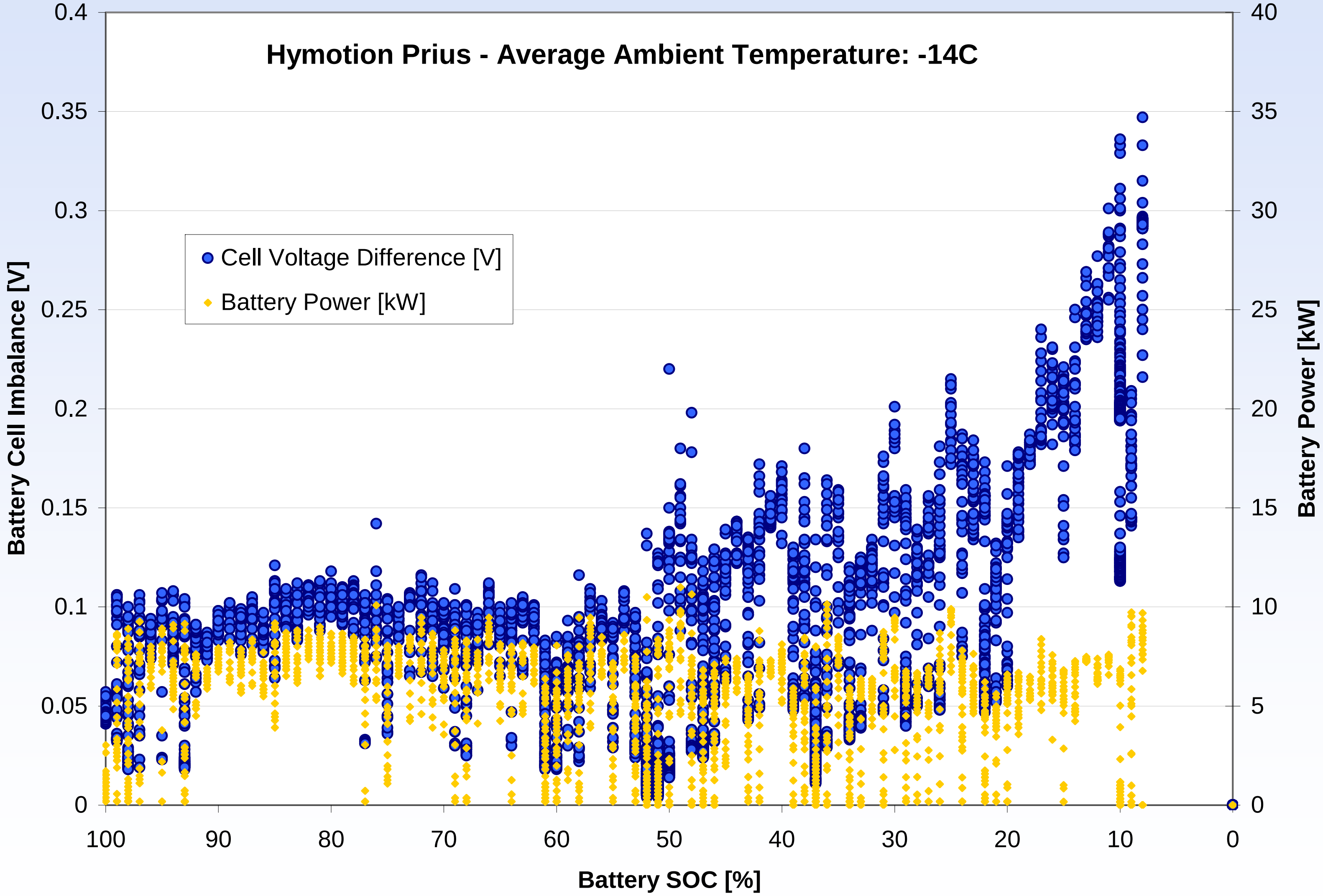


PHEV'09 Plug-In Hybrid and Electric Vehicles September 28 to 30, 2009 – Montreal
Véhicules électriques et hybrides rechargeables 28 au 30 septembre, 2009 – Montréal

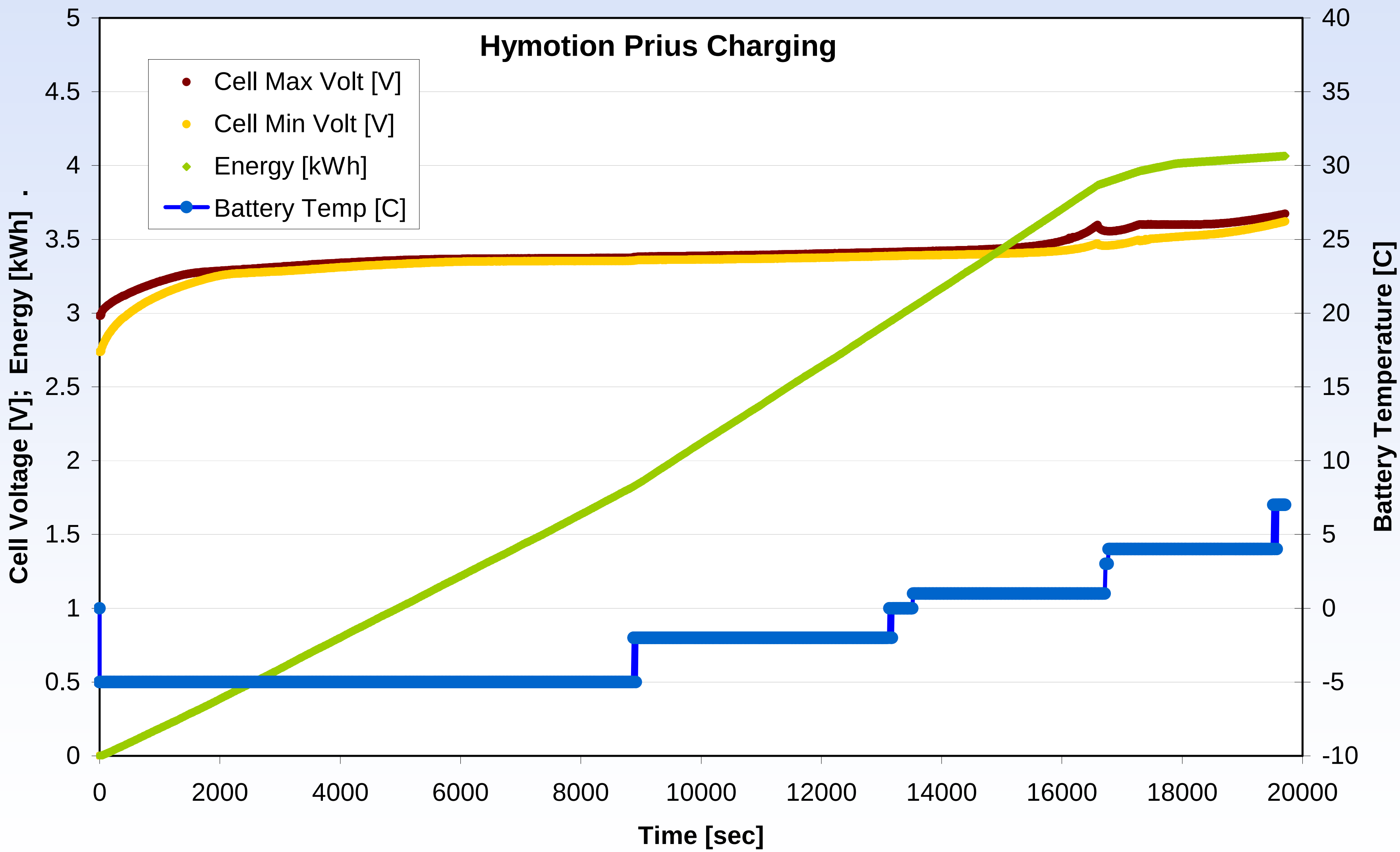
Battery Cells have Moderate Imbalance at Mid Temperatures



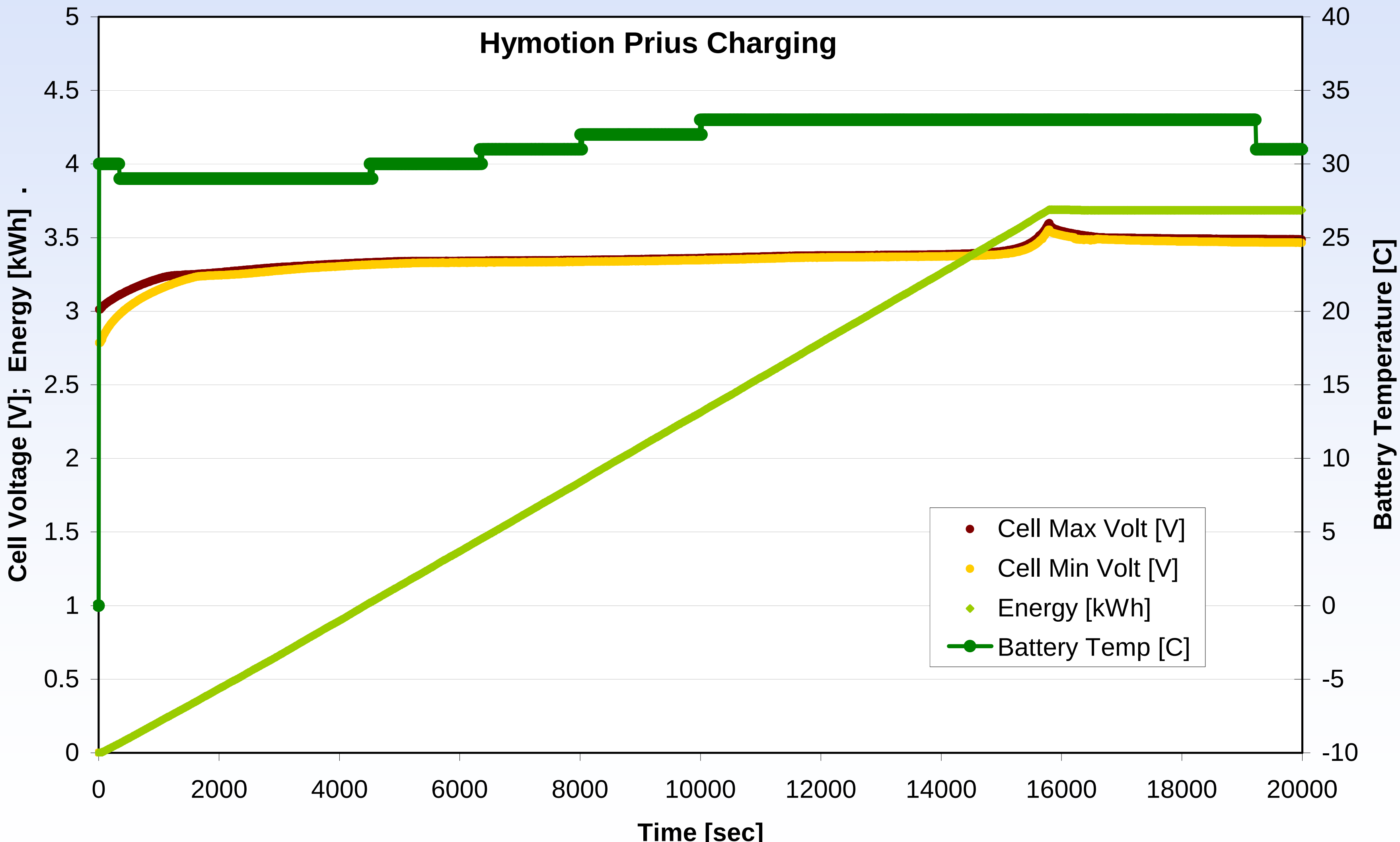
Battery Cells have Increased Imbalance at Low Temperatures



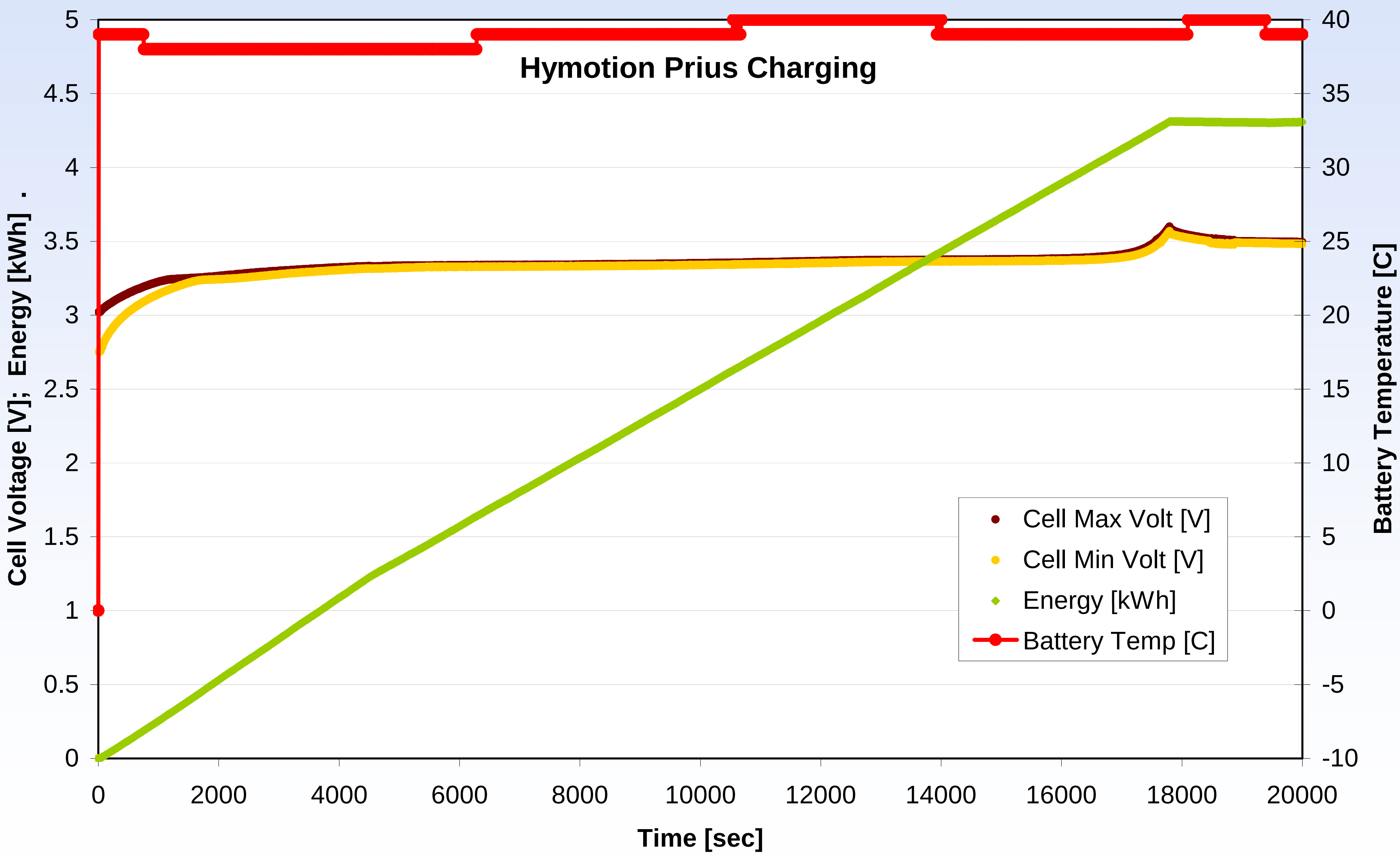
Charging At Low Temperature Requires Increased Energy for Cell Balancing



Charging At Mid Temperature Does Not Require Increased Energy for Cell Balancing



Charging At Higher Temperature Does Not Require Increased Energy for Cell Balancing



Summary

- **Extreme ambient temperatures significantly impact PHEV fuel economy**
  - **Engine operating time increases**
  - **Accessories utilization increases**
- **Prius battery control system (calibrated for NiMH) is not able to take full advantage of possible benefits of Li-Ion technology at extreme temperatures**
- **Battery capabilities show a slight decrease at low temperatures**
  - **Reduced energy capacity**
  - **Increased internal resistance**
  - **Increased cell imbalance which could lead to further reduction in capacity**

Acknowledgement

This work is supported by the U.S. Department of Energy's Vehicle Technologies Program

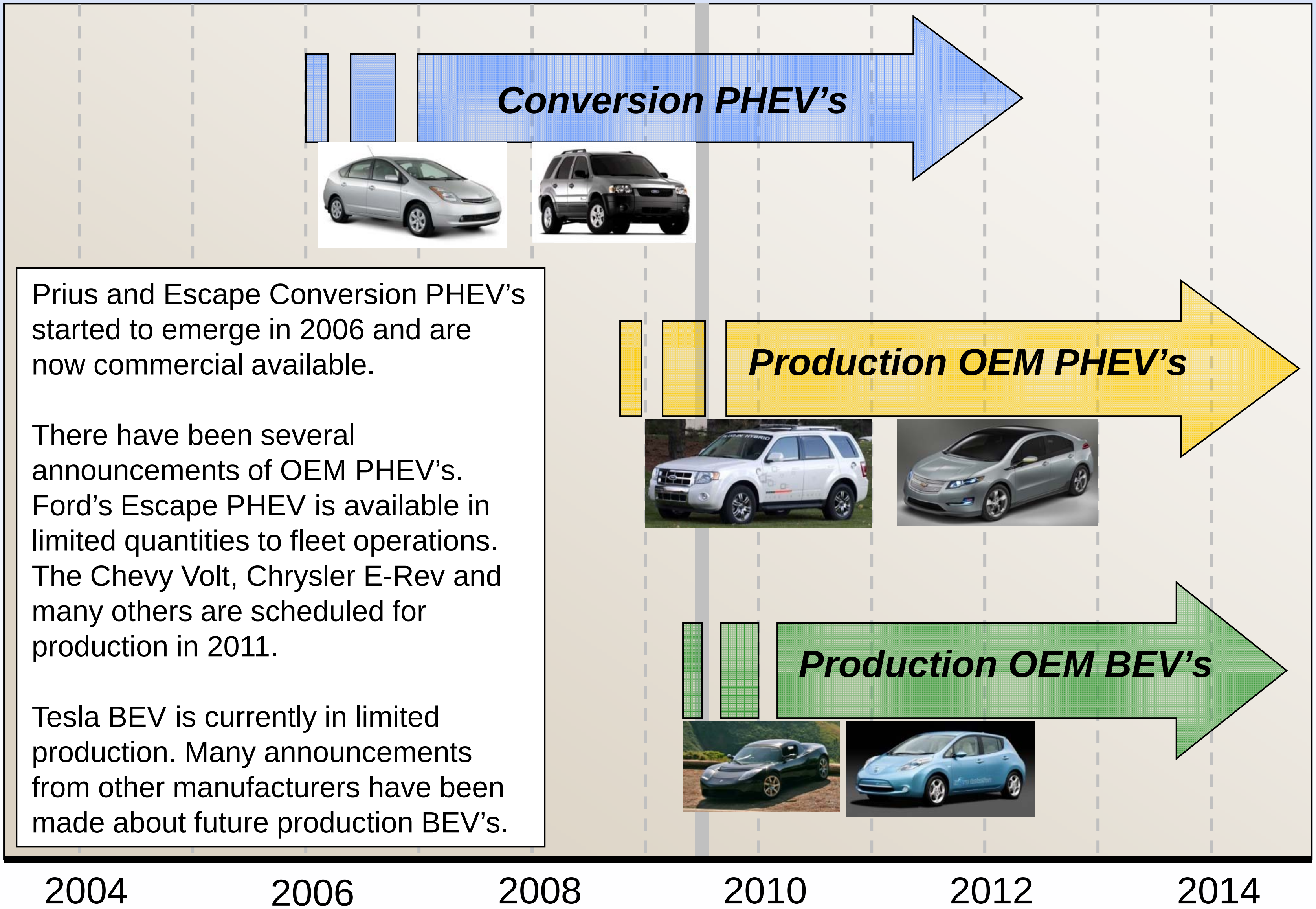
Additional Information

http://avt.inl.gov
or
http://www1.eere.energy.gov/vehiclesandfuels/avta/

INL/CON-09-16628

Backup Slides

Timeline of Advanced Vehicle Availability

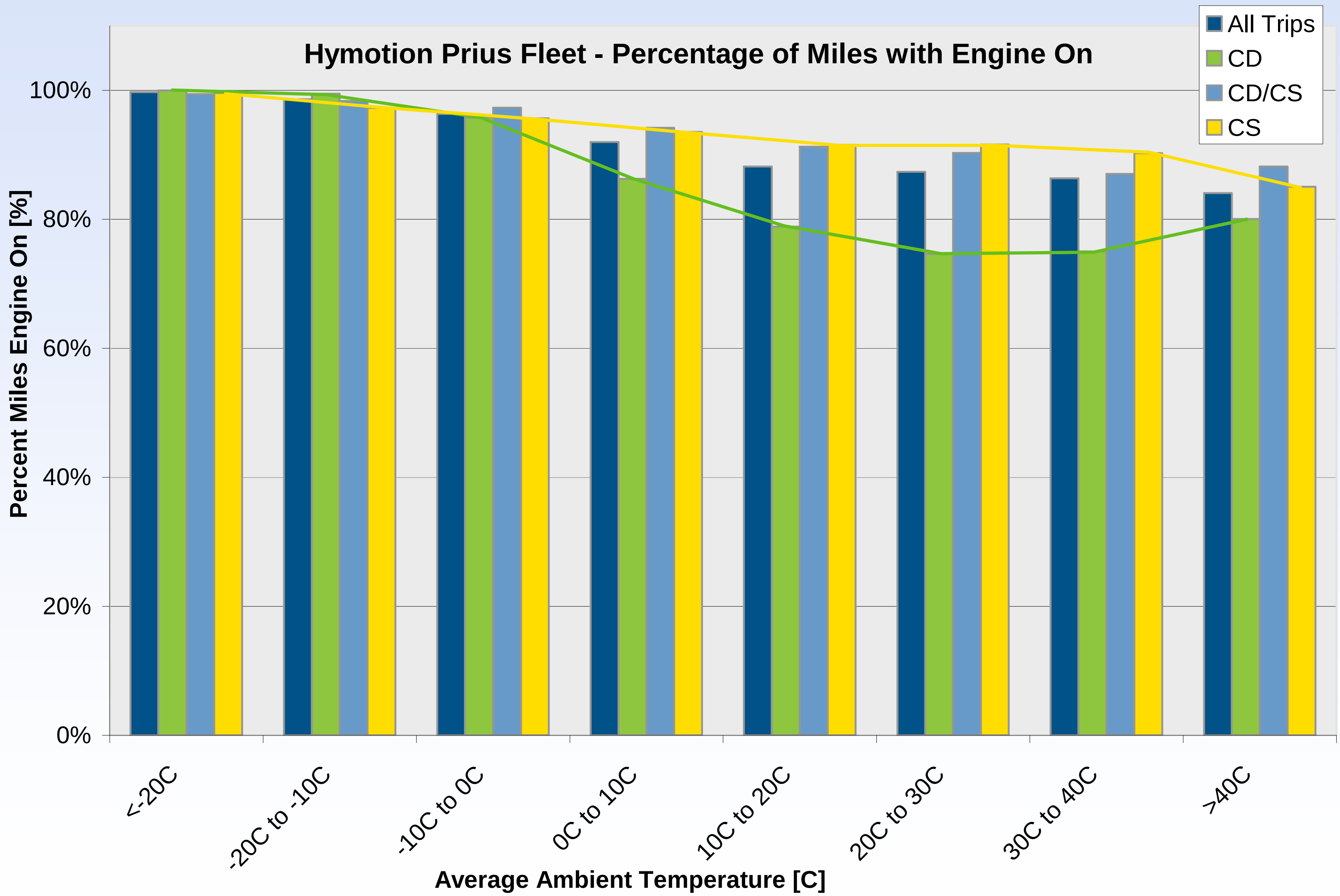


Prius and Escape Conversion PHEV's started to emerge in 2006 and are now commercial available.

There have been several announcements of OEM PHEV's. Ford's Escape PHEV is available in limited quantities to fleet operations. The Chevy Volt, Chrysler E-Rev and many others are scheduled for production in 2011.

Tesla BEV is currently in limited production. Many announcements from other manufacturers have been made about future production BEV's.

Engine Operation is a Main Factor for change of Fuel Economy for PHEV’s



Other PHEV Testing

- Bidirectional vehicle-to-grid (V2G) charging study
  - 6 kW and 20 kW levels, using lithium PHEV batteries, V2Green cellular charging control. Documents infrastructure requirements and costs
- City of Seattle \ V2Green lead time-of-day charging demonstration on 13 Seattle-area PHEVs. Includes INL battery impact analysis. Uses wireless charging control
- Developing vehicle-based battery test bed research project for testing PHEV and BEV batteries in various vehicle and charging operating scenarios
- Conduct vehicle \ battery testing on PHEVs when received via DOE's Technology Assistance and Demonstration Activity

Other PHEV Testing – cont'd

- Tacoma Power charging infrastructure study
  - AVTA and Tacoma Power are collecting data on one section of administration building (800 amp, 480 volt, 3 phase load) and PHEV charging infrastructure
  - Document demand and energy profiles of PHEV charging as portion of facility profiles
  - WiFi local energy meter (LEM) data collection system

PHEV Charging Infrastructure Cost Report

- Analyzes PHEV infrastructure requirements in single and multi-family residential, and commercial facilities as well as driving trends. No site specific costs
- Charging infrastructure equipment/administrative costs:
  - Levels 1 (120V, 15 or 20 amp) and 2 residential
  - Levels 1 and 2 (208/240V ~40 amp) apartment complex
  - Level 2 commercial facility
- Battery sizes & charge times for various PHEV platforms
- Power electronics & battery costs for PHEV platforms

Level 1 Residential	Labor	Material	Permits	Total
EVSE (charge cord)	- -	$250	- -	$250
Residential circuit installation (20A branch circuit, 120 VAC/1-Phase)	$300	$131	$85	$516
Administration costs	$60	$43	$9	$112
Total Level 1 Cost	$360	$424	$94	$878

Report @ http://avt.inl.gov/pdf/phev/phevInfrastructureReport08.pdf